

REPORT DOCUMENTATION PAGE

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1 item enclosed

*late
notification*

✓ spreadsheet
✓ DTS

MEMORANDUM FOR PRR (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO)

9 June 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0143
Bruce Farmer, et. al., "Covering Achievements of the US Air Force Thrust Cell Technologies Program and Light
Weight Thrust Chamber Assembly Program"

ASM Aerospace Materials Technology Conference

(Public Release)

Advanced Materials and Processes for Rocket Engines

Thrust Cell Technologies Program

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Covering Achievements of the US Air Force
Thrust Cell Technologies Program

and

Light Weight Thrust Chamber Assembly Program

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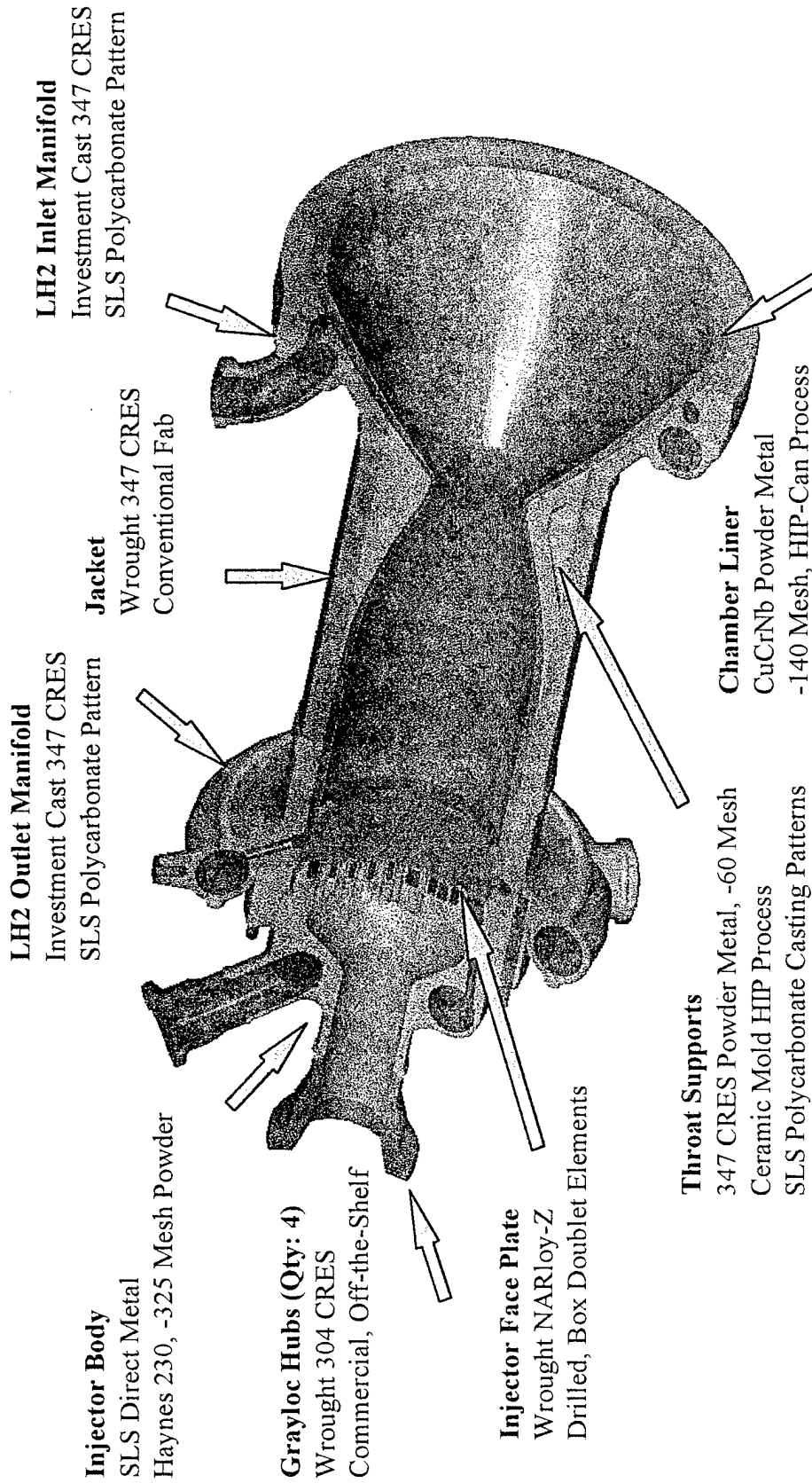
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Thrust Cell Engine Assembly

Thrust Cell Technologies Program

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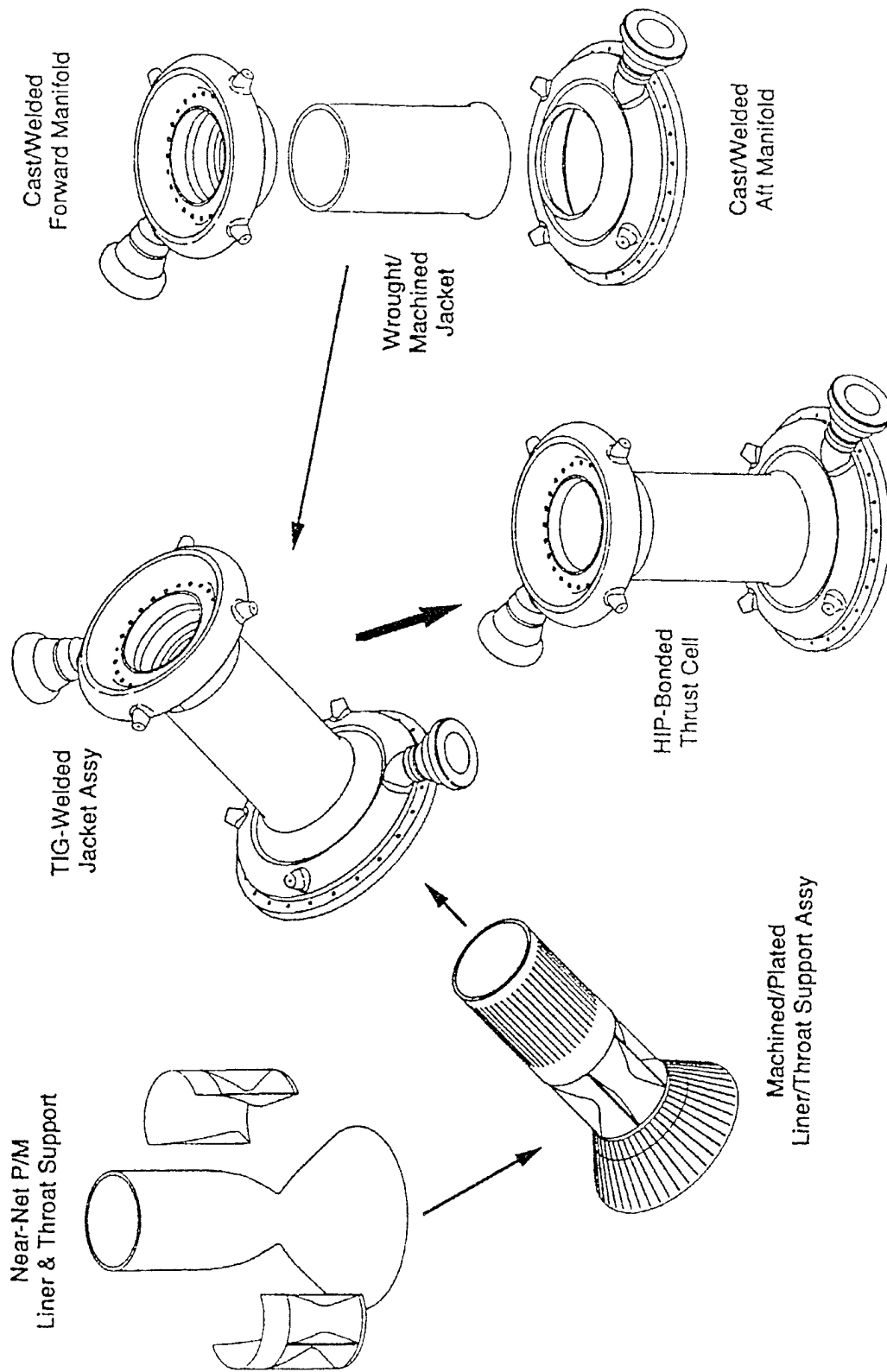
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Engine Assembly Sequence

Thrust Cell Technologies Program

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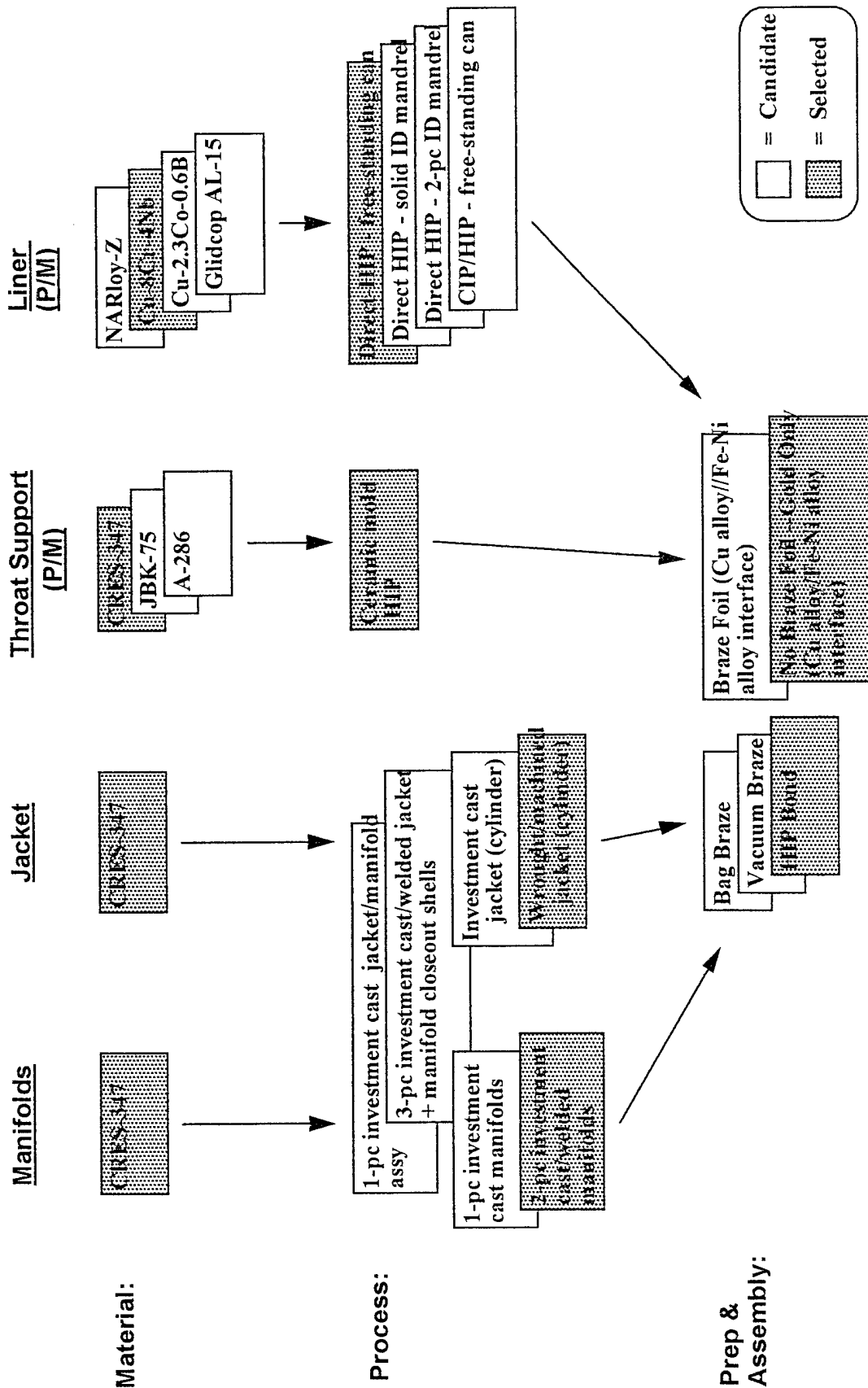
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Material & Process Selection

Thrust Cell Technologies Program

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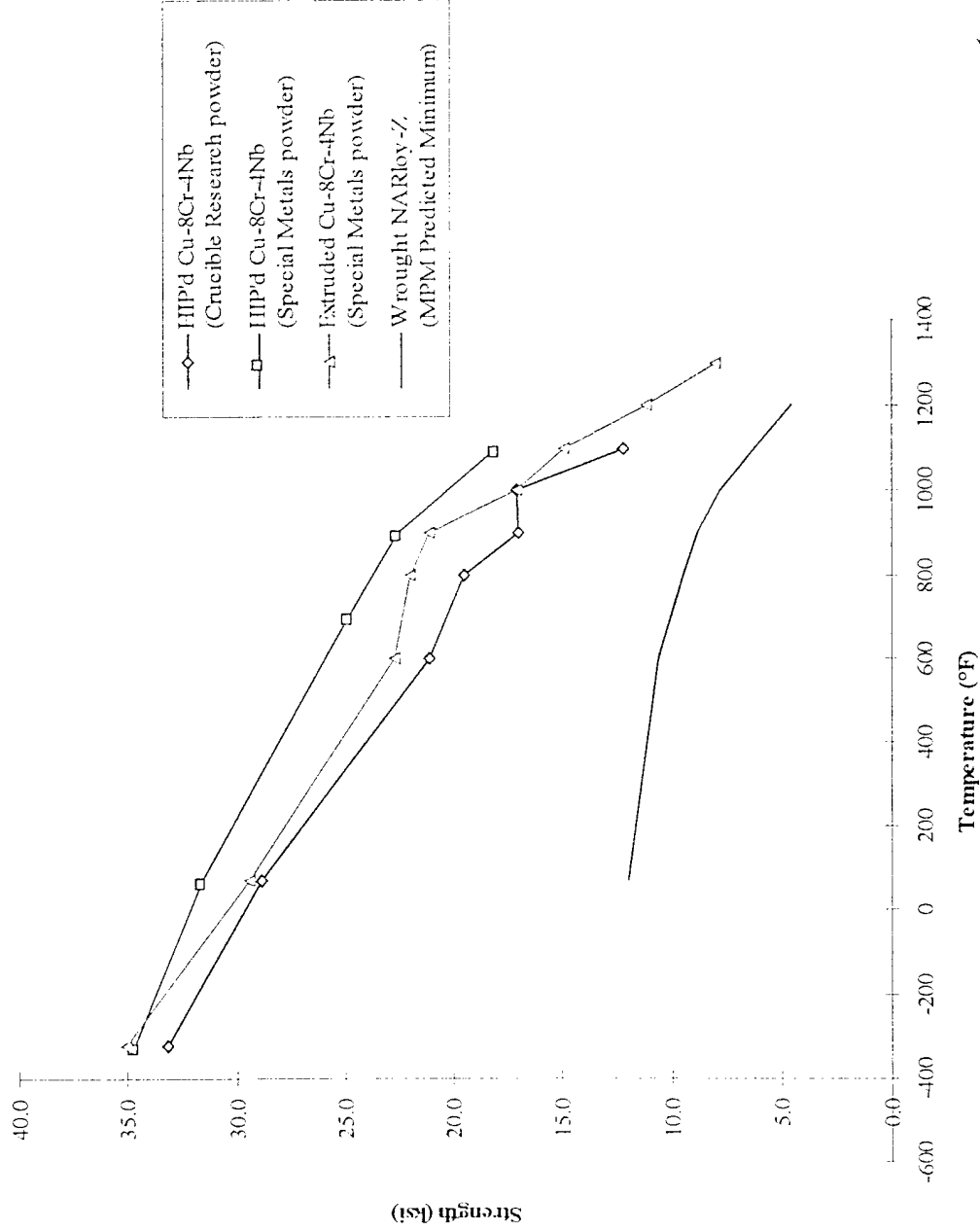
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Cu-8Cr-4Nb Properties

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Yield Strength after simulated braze cycle @ 1700°F



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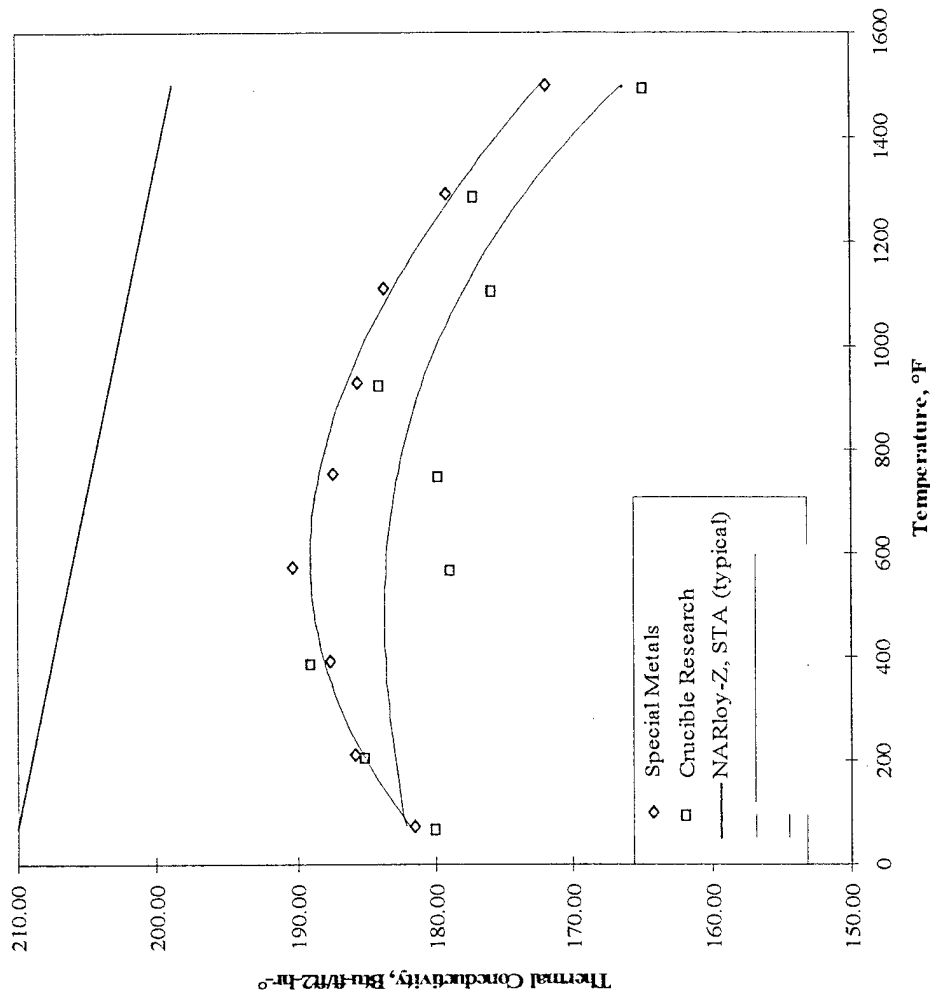


Cu-8Cr-4Nb Properties

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Thermal Conductivity of HIP'd P/M Cu-8Cr-4Nb



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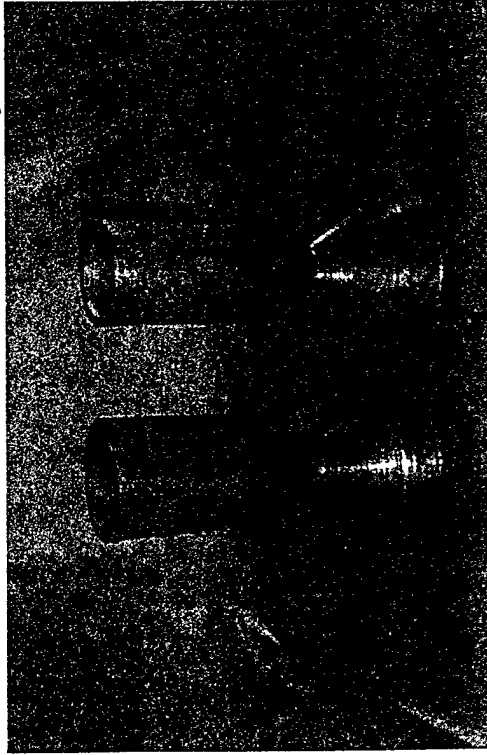
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Thrust Chamber Liners

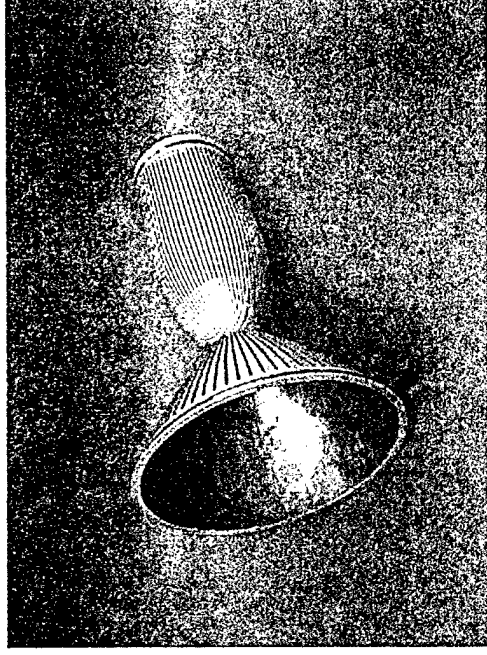
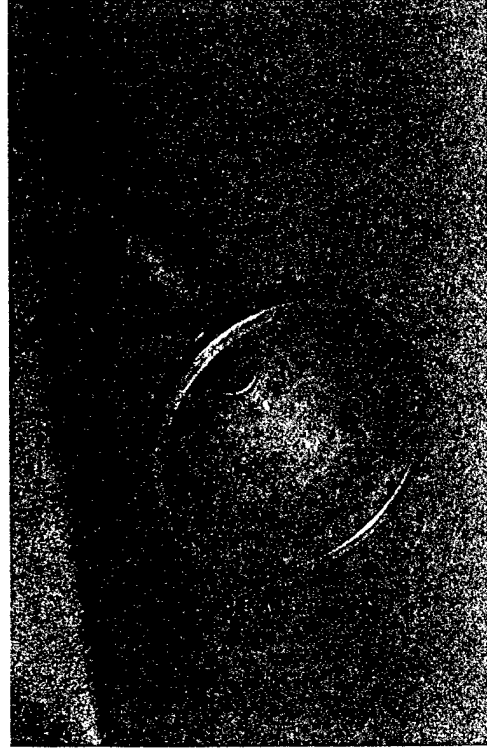
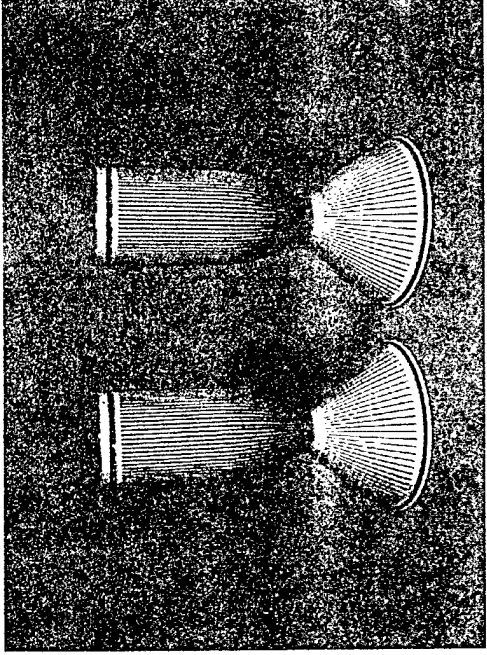
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Cu-8Cr-4Nb Powder Metal Liner Preforms



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Finished Liners, Gold Plated



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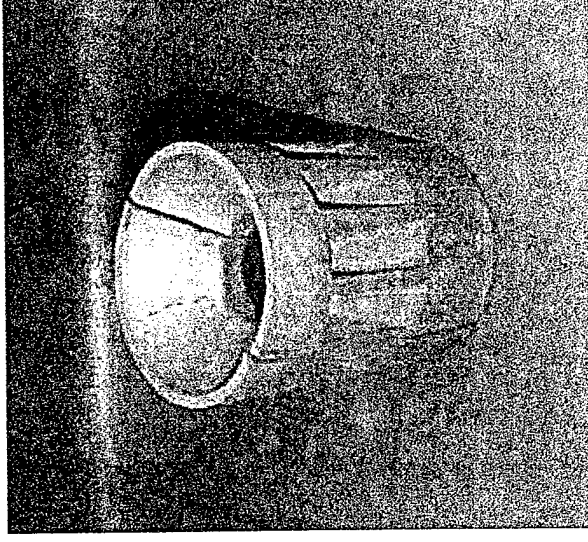
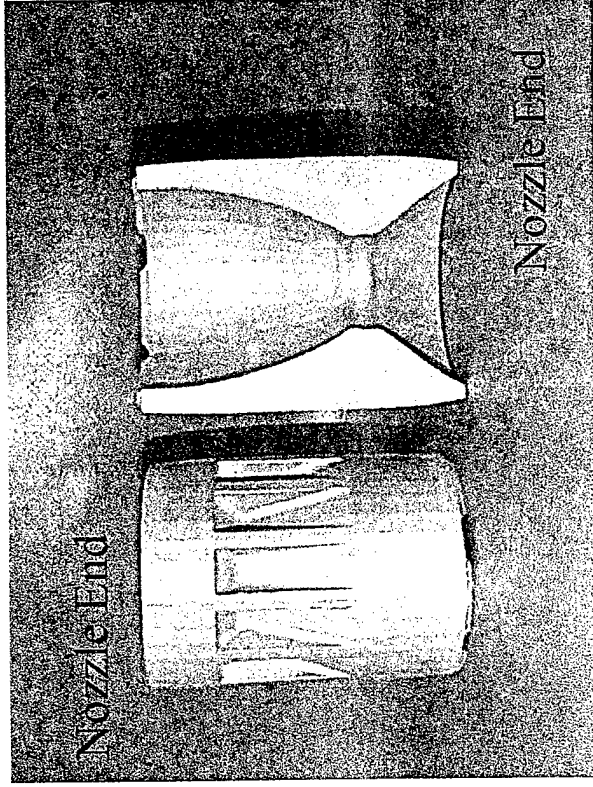
Throat Support Powder Metal Preforms

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Ceramic Mold Process

Material: -60 Mesh 347 CRES



- Powder metal affords added flexibility in properties through alloy formulation and control of grain sizes
- Lost-wax investment mold made from SLS polycarbonate patterns
- Mold filled with 347 CRES, packed in pressure transfer medium in a steel can and HIP'ed

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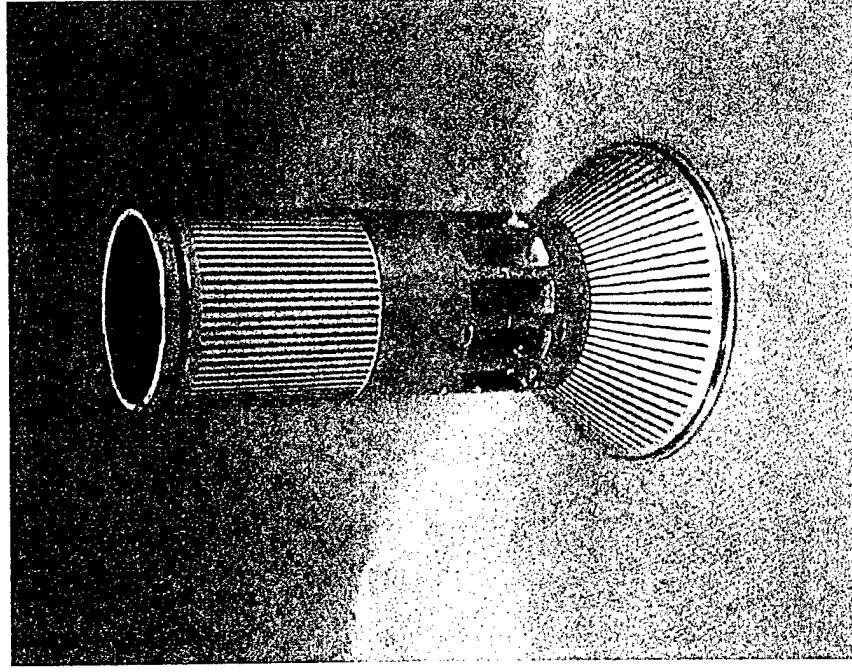
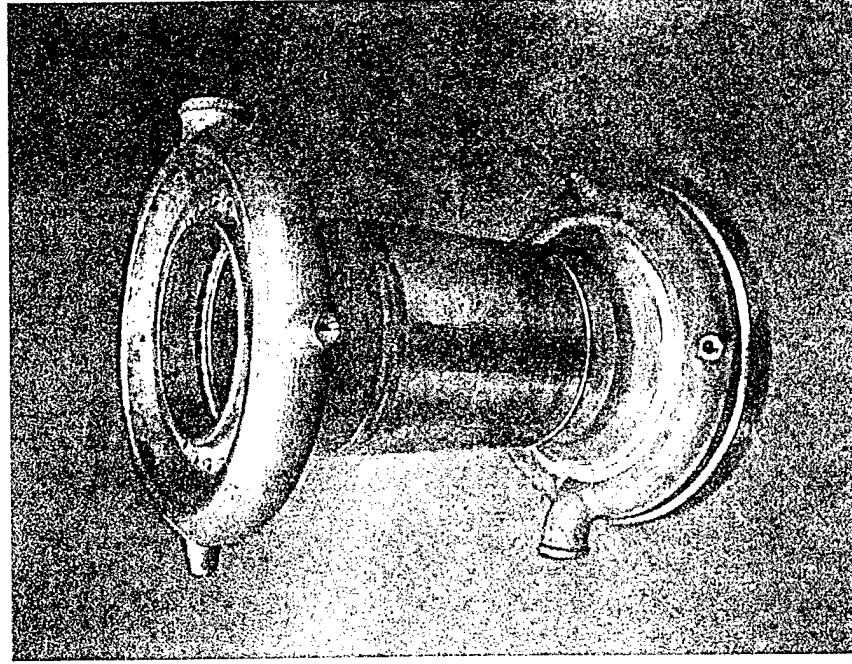


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Structural Jacket and Liner Subassembly

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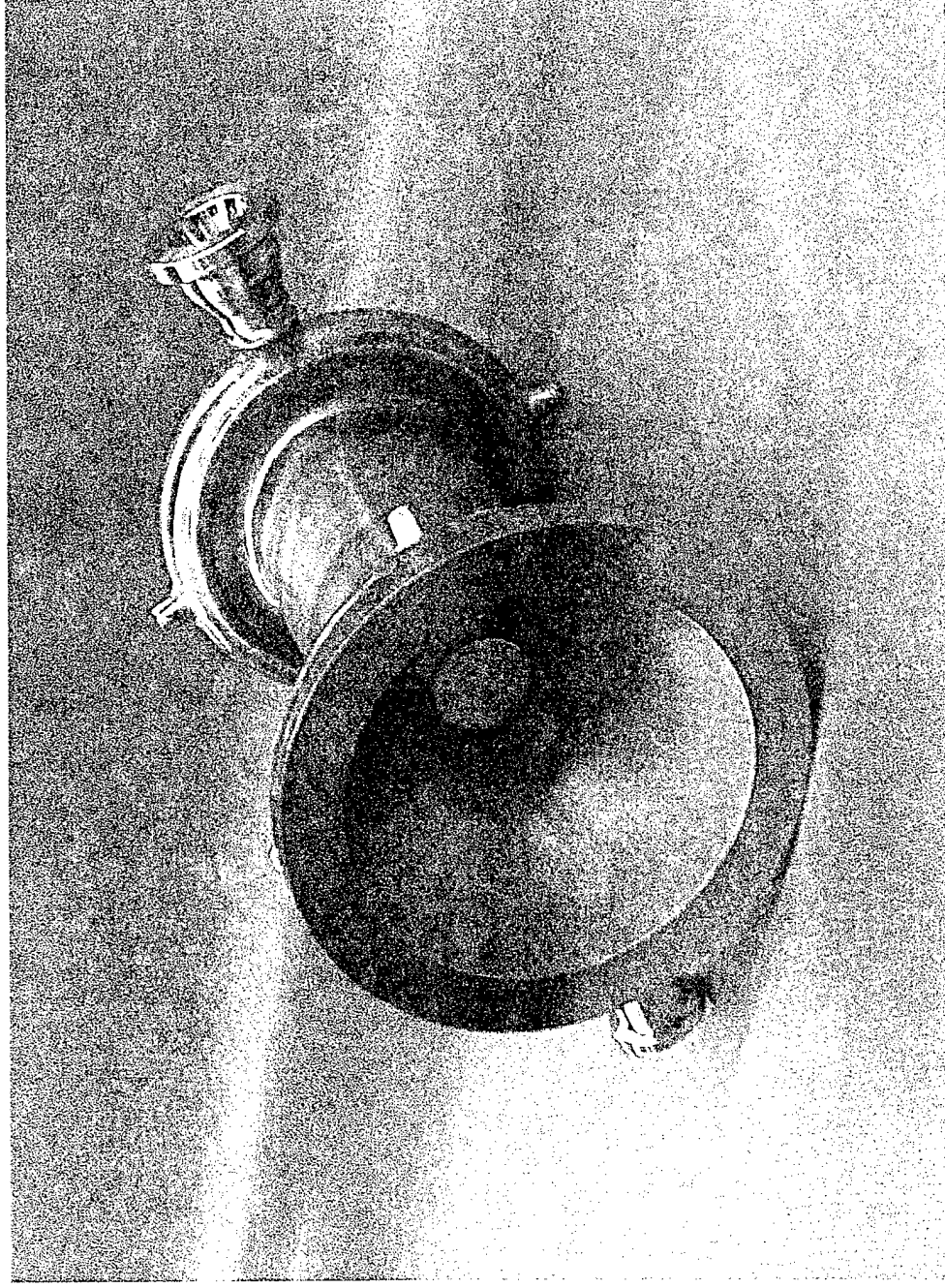
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Completed Combustion Chamber

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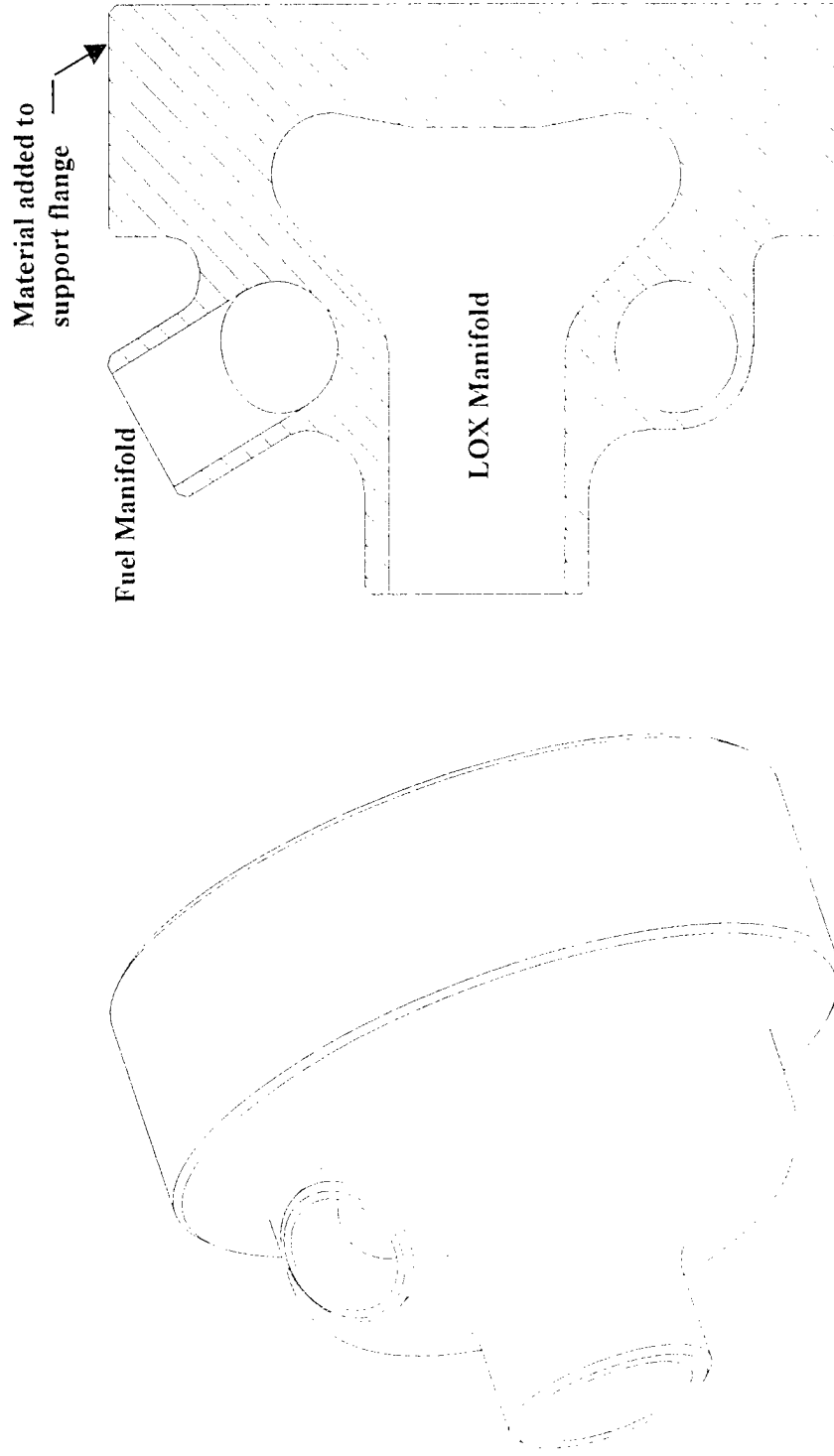
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Injector Body Preform - Rapid Prototype Model

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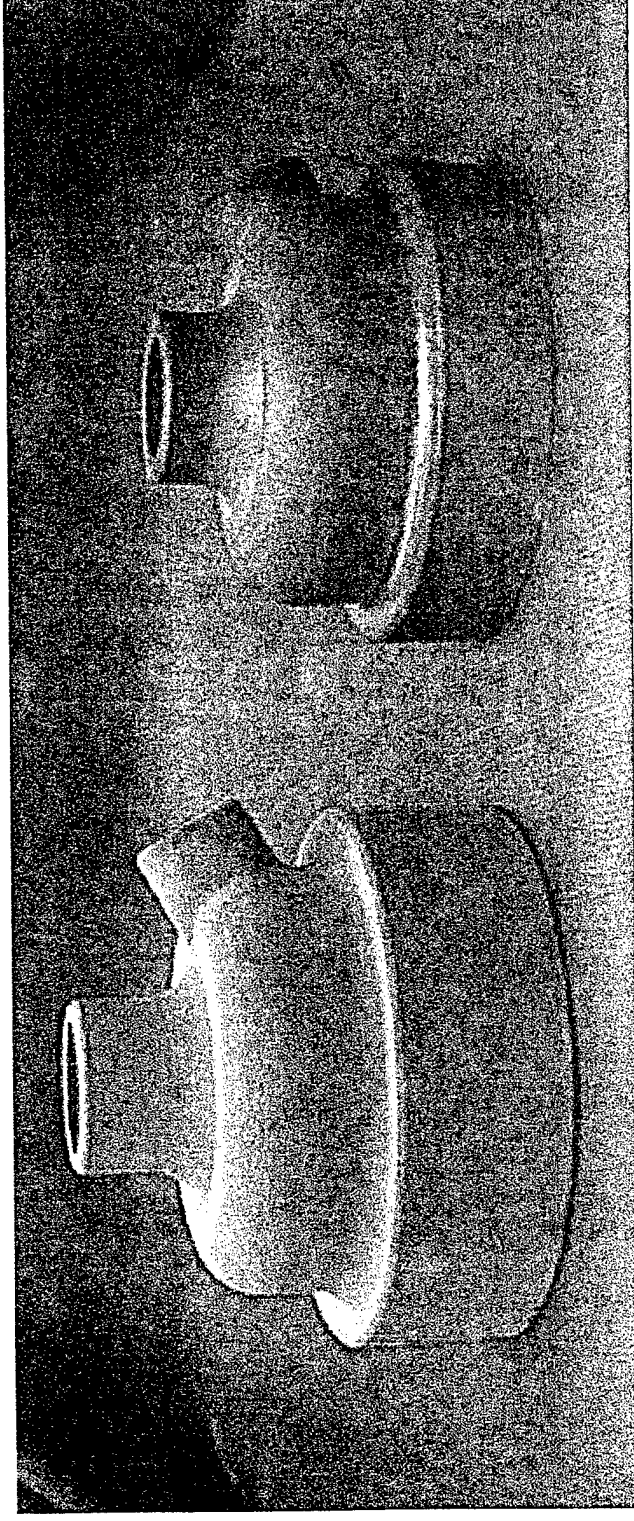
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SLS Direct Metal, Haynes 230 Injector Body Preform

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- Injector body at left is in the “green” state
- Injector body at right is consolidated and HIP’ed to full density, 99.3% of theoretical
- No sagging or significant cracking was observed
- Six green parts built and sintered to achieve success

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SLS Haynes 230 Properties

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Haynes 230 flat and round tensile bars fabricated by SLS

- As sintered, no surface polishing
 - $F_{tu} = 97$ ksi; elongation = 5%
- Sintered and HIP'd
 - $F_{tu} = 117$ ksi; $F_{ty} = 56$ ksi; elongation 25%

Wrought Haynes 230 tensile properties

- Rolled and annealed plate
 - $F_{tu} = 125$ ksi; $F_{ty} = 57$ ksi; elongation = 50%
- Investment casting
 - $F_{tu} = 89$ ksi; $F_{ty} = 47$ ksi; elongation = 35%

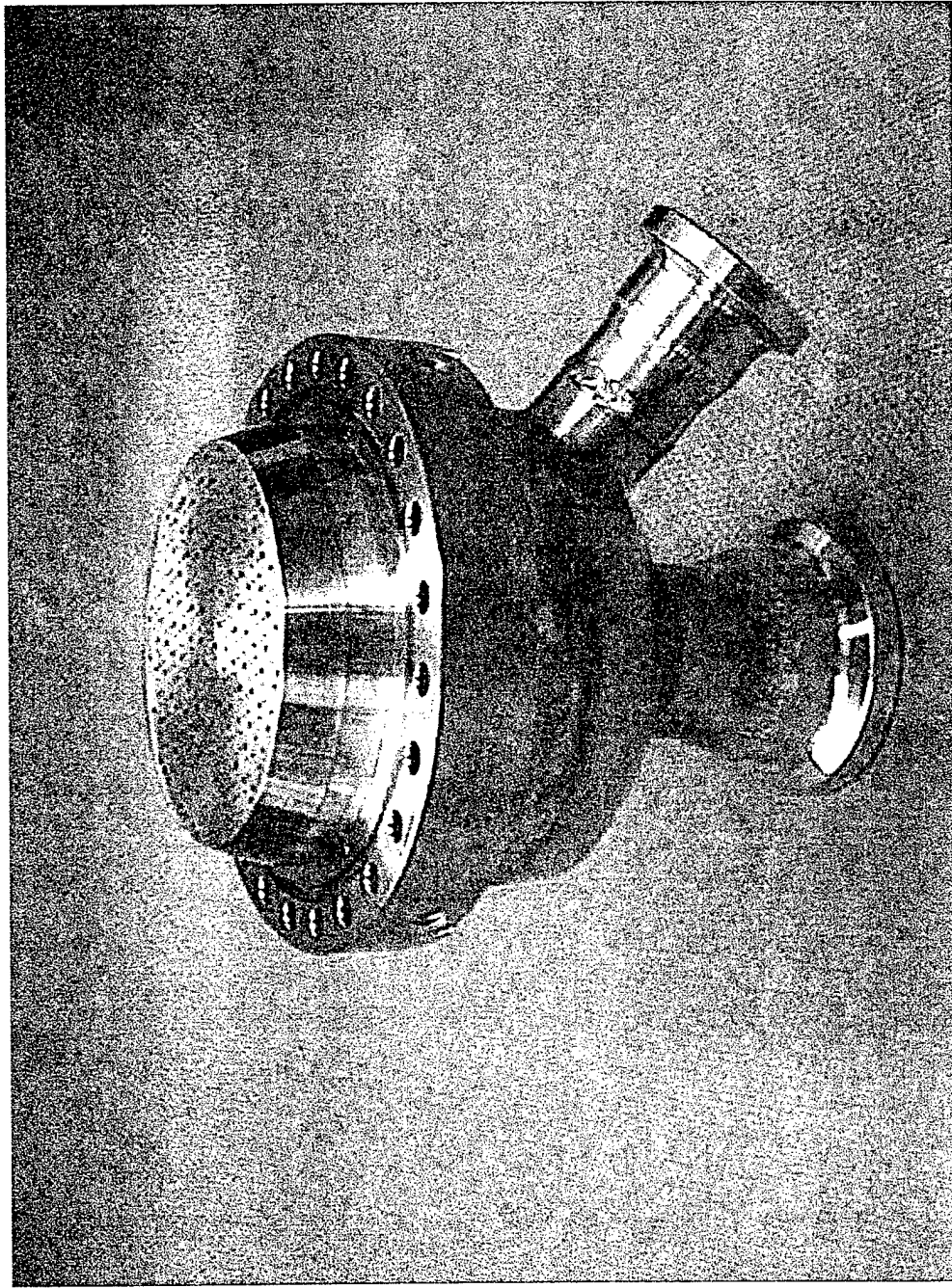
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Injector Assembly

Thrust Cell Technologies Program

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LWTCA Program Summary

Light Weight Thrust Chamber Assembly Program

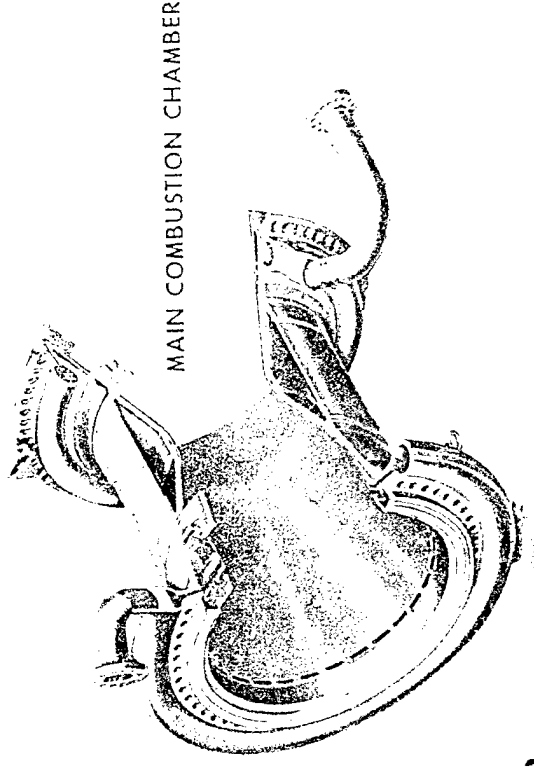
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Objectives

- Demonstrate technology for 400 Klb thrust LOX/hydrogen booster engine
 - 40% reduction in weight
 - 50% reduction in cost
 - 75% reduction in part count
 - 3% increase in specific impulse

Hardware

- Chamber and injector MTD's
- Chamber and injector sub-scale, hot-fire test hardware



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Advanced Materials Baseline Design

Light Weight Thrust Chamber Assembly Program

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Allied Signal AS800 Si_3N_4 Baseline

- Throat Supports
 - Two-piece construction
 - Near-net halves, final machined (diamond ground) I.D. and O.D.
 - Compatibility with HIP bonding process
- Structural Jacket
 - Gel-cast forward and aft propellant manifolds
 - Gel-cast structural jacket
 - Final machined I.D. for assembly and HIP bonding
- Chamber Liner made from NARloy-Z
 - Proven liner material, well characterized
 - Joinable to silicon nitride
 - Slotted wall construction
 - Standard aspect ratio channels

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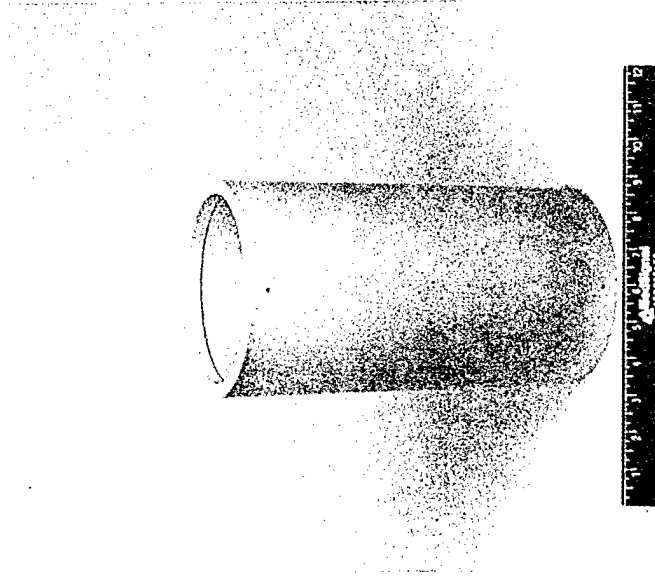


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Final Machined Cylindrical Braze Specimens

Light Weight Thrust Chamber Assembly Program

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- Two 6" Height Specimens
Delivered 8/98
- One 11.3" Height
Specimen Delivered 11/98
- Large Component Processing
Experience will Benefit MTD
Hardware Development

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Minimize Post-Bond Stresses

Light Weight Thrust Chamber Assembly Program

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- **Bond Joint Residual Stress due to CTE Mismatch**
 - Select Geometry to Minimize Free-edge Stress Singularity
 - bondline thickness
 - wedge angle
 - scarf bond ends
 - Selection of Materials
 - Compatibility of bimaterial and braze alloy
 - Include Inelastic Properties
 - temperature-dependent stress-strain curves
 - time-dependent properties

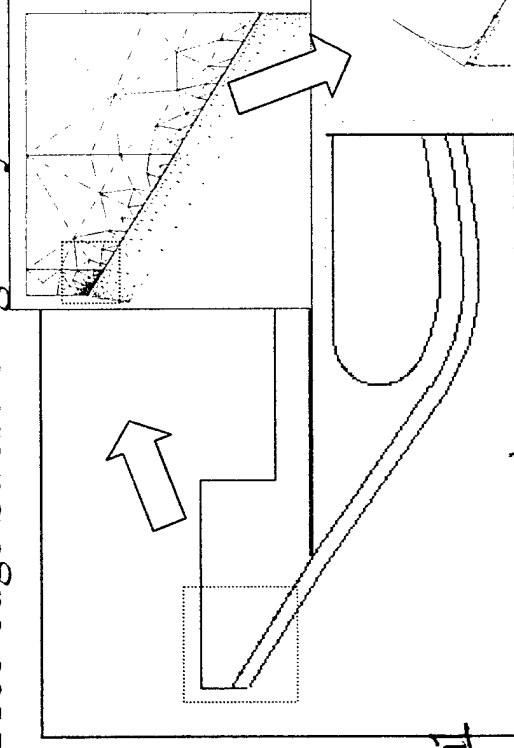


FIGURE 1-1
BOND JOINT GEOMETRY
AND STRESS DISTRIBUTION

FIGURE 1-2
BOND JOINT GEOMETRY
AND STRESS DISTRIBUTION

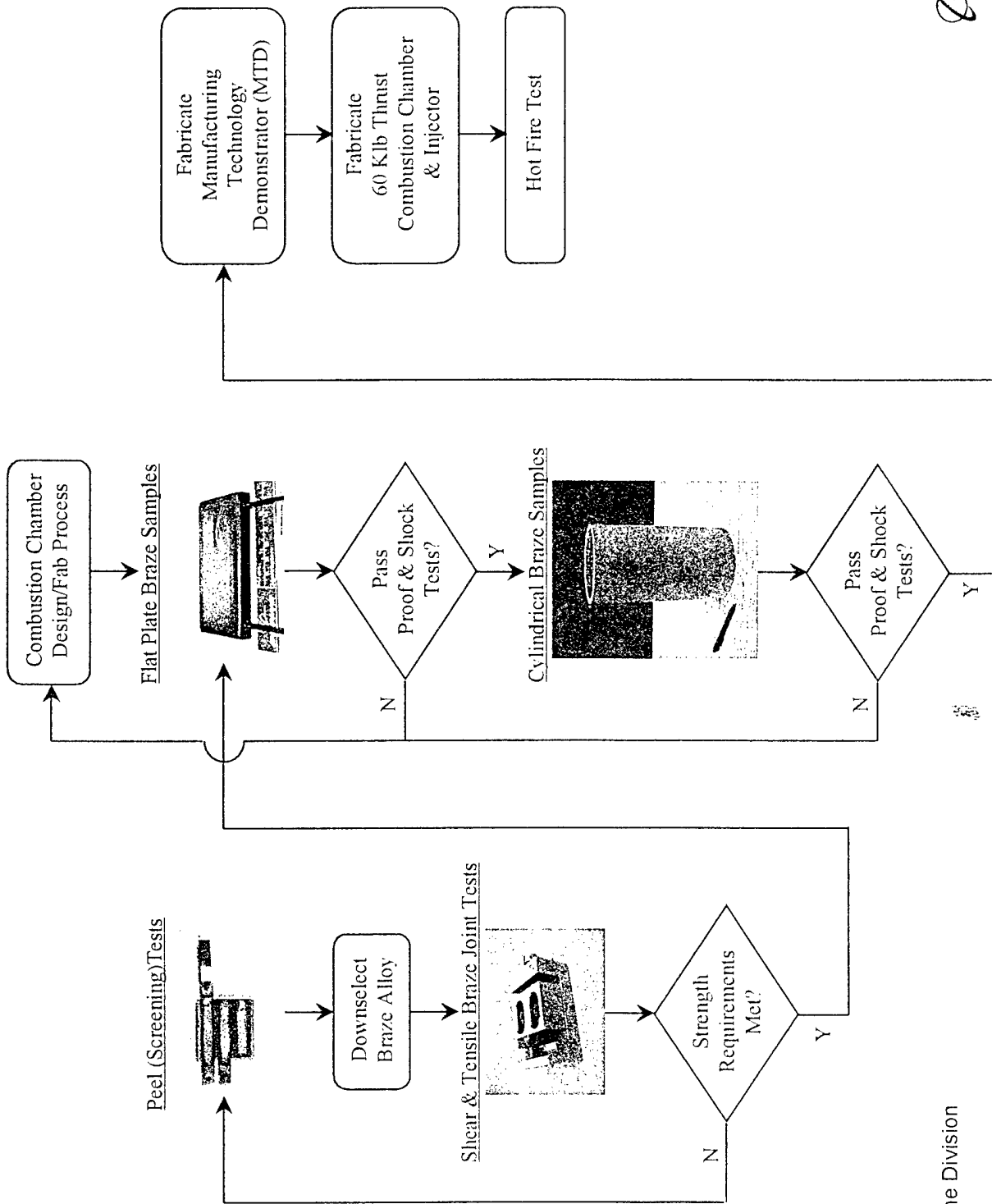
FIGURE 1-3
BOND JOINT GEOMETRY
AND STRESS DISTRIBUTION

FIGURE 1-4
BOND JOINT GEOMETRY
AND STRESS DISTRIBUTION

Combustion Chamber Joining Logic

Light Weight Thrust Chamber Assembly Program

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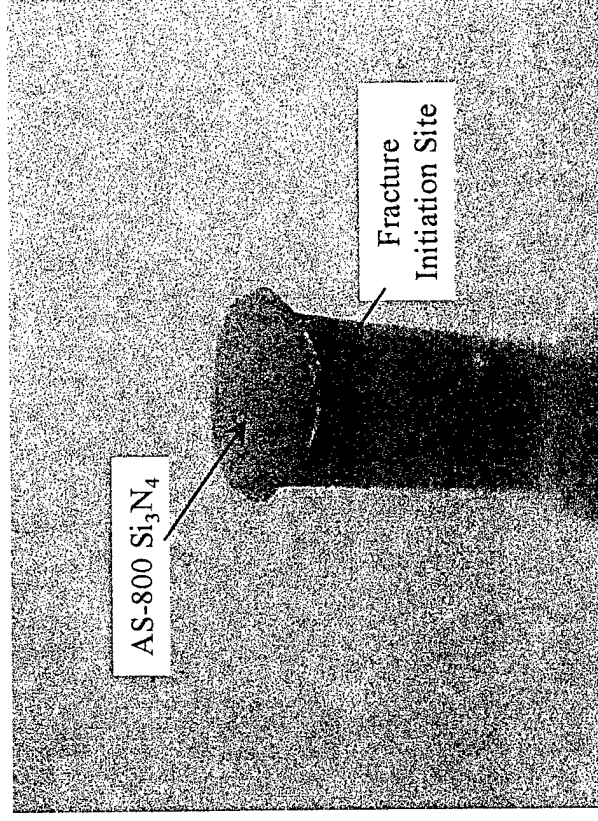
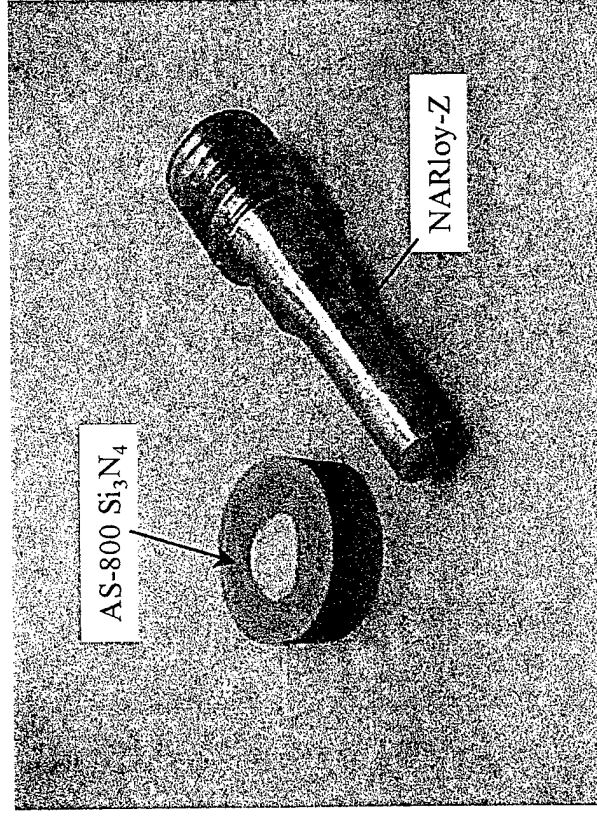
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Fracture Behavior - "New" Tensile Specimen

Light Weight Thrust Chamber Assembly Program

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- Higher joints strength correlates with full braze fillet 360 degrees

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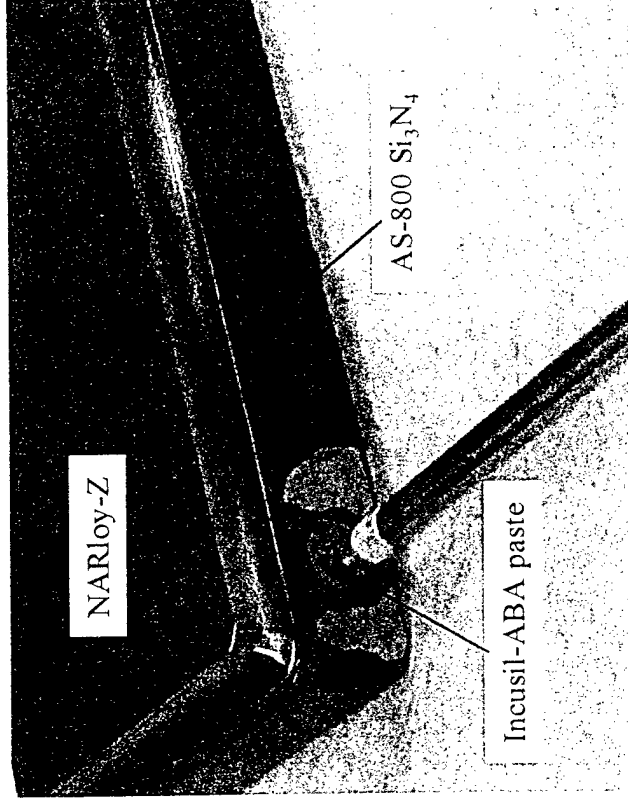


Design Features

Light Weight Thrust Chamber Assembly Program

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- Edges of NARloy-Z plate chamfered to reduce residual stress concentration at free edges
- Corners rounded to reduce stress concentration
 - Crack initiated at corner of silicon nitride plate in first braze sample
- Stainless steel tubes brazed with Incusil-ABA paste during same braze cycle



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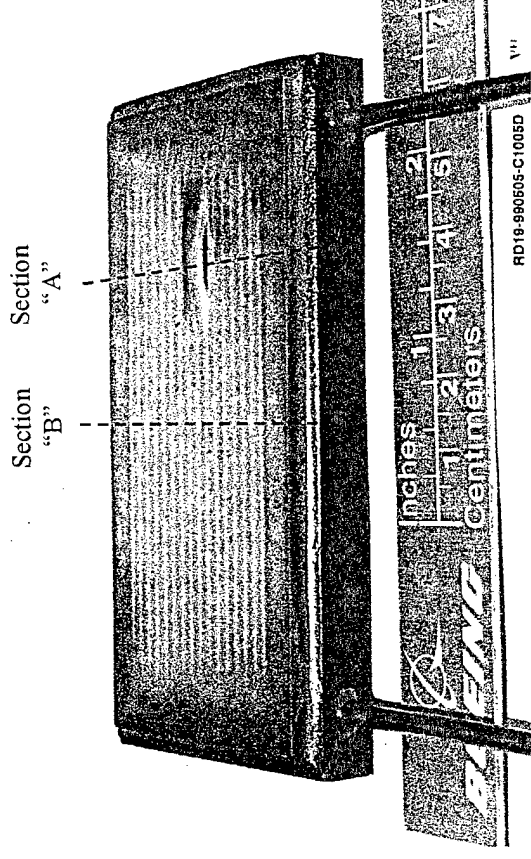
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Destructive Testing

Light Weight Thrust Chamber Assembly Program

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- Survived 5 proof pressure cycles at 7700 psig
- Pressured to failure at 10,500 psig
- Cross-sectioned to determine failure mode



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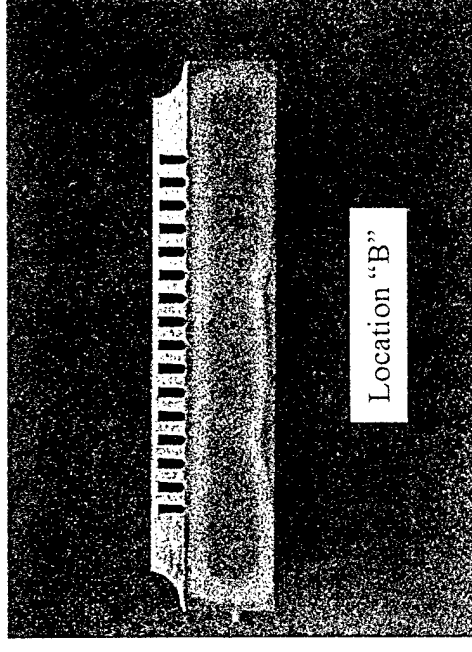
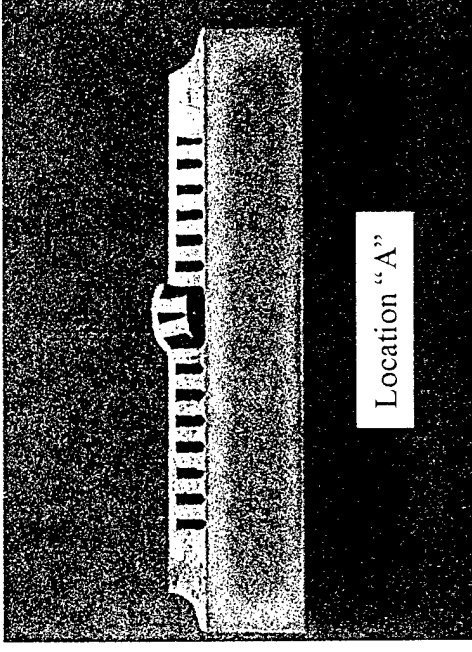
Destructive Testing (cont.)

Light Weight Thrust Chamber Assembly Program

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- Failure initiated in braze joint
- Evidence of excessive pressure during brazing
 - Excessive braze fillets
 - Little in any braze alloy left in joint

Little if any ... ?



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Future Work

Light Weight Thrust Chamber Assembly Program

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- Determine sensitivity of brazing pressure to joint quality i.e., fillet size, braze alloy thickness in joint
- Conduct cryogenic flow tests, i.e. LH₂, to simulate transient loads from CTE and delta-T differences during start-up
- Scale up from flat plate to cylindrical braze samples
- Fabricate manufacturing technology demonstrator (MTD) and hot-fire quality, sub-scale combustion chamber

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